It would appear as if the mechanical properties of a gas at ordinary pressures and up to extreme exhaustions (setting aside the minute deviations from Boyle's law, &c.), were completely defined by two constants, suppose the density at a given pressure and the coefficient of viscosity, but at the high exhaustions at which phenomena of "ultra-gas" begin to appear, specific differences came in, to include which an additional constant, or perhaps more than one, requires to be known.

## II. "Notes on the Earthquakes of July, 1880, at Manila." By Commander W. B. Pauli, R.N., Her Britannic Majesty's Consul at Manila. Received January 18, 1881.

*The following "Notes" have been communicated from the Foreign Office, by direction of Earl Granville, K.G., F.R.S.*

I was unfortunately obliged to leave Manila last June on sick leave, and the news of the late disastrous earthquakes reached Europe shortly after my arrival.

My knowledge of the locality enabled me to realise the extent of the calamity even with the bare details given by the telegrams.

I have collected the fullest information obtainable at this distance, chiefly from local papers and letters from friends, but by far the most important data I have received are contained in the scientific observations sent me by Father Faura, the Director of the Municipal Observatory at Manila, who being a pupil of the late Father Secchi, of Rome, and himself taking keen interest in science, chiefly in relation to storms and earthquakes, is a particularly fit person for his present post.

The Manila Observatory is now furnished with seismographical instruments, by which the accompanying diagrams of the chief shocks were obtained.

These, with the translation of Father Faura's observations on them, I trust may be of interest, especially as this is the first scientific account of earthquakes in the Philippine Islands, where they are so frequent and so violent.

To this account I have appended further information derived from other sources respecting the course and extent of the disturbances, but have purposely omitted the details of the personal experiences of individuals and the loss sustained in life and property, confining my remarks to such accounts as bear directly on the phenomena in a scientific point of view.

A short preliminary account of the volcanic systems of Luzon, the seat of the late earthquakes, may prove a useful introduction.

Don José Centeno y Garcia, Inspector-General of Mines to the

Philippine Government, in a work called "Memoria Geologico Minera de los Islas Filipinas," observes:—"That the volcanic action in the Philippine Archipelago is not displayed in an arbitrary or irregular manner, but, on the contrary, is exercised by defined lines almost parallel to each other, whose direction may be fixed as from N.N.W. to S.S.E., thus showing two parallel systems, which to distinguish from each other we will call the system of Taal, and that of Mayon, being the names of the two volcanoes of the greatest and most frequent activity in the two systems."

The first, viz., the system of Taal, commences in the north of Luzon, and after traversing the greater part of the island, including in its course the active volcano of Taal, is lost in the sea of Mindoro, to reappear in other islands of the Archipelago.

The second system, "of Mayon," is situated to the eastward of the first, and is represented by the magnificent active volcano of Mayon of 8,000 feet altitude, and although parallel to the first, does not extend farther to the north than the extinct volcano of Isero, in the province of South Camerines, in Luzon, but traverses the southern portion of the island, and includes the active volcano of Bulasan, at the extreme southern point of Luzon; it appears again in other islands, especially in the large island of Mindanoa.

Señor Centeno observes that these two distinctly parallel lines in Luzon, with a distance of about 120 miles between them, after leaving that island, approach each other so as to be only 64 miles apart in Mindanoa, and in his opinion join each other in the southern group of the Mollucas.

The present earthquakes extended from Vigan, in the north, to Tayabas in the south, being in the line of the system of Taal, which volcano showed considerable and unusual activity during the disturbance. The volcano of Mayon, on the contrary, is reported as being in its normal state, emitting no more than its usual amount of smoke, although the volcano of Bulusan (in the system of Mayon, and far to the southward of that mountain), which seldom shows signs of activity, had recommenced to throw up smoke. This would appear to corroborate Señor Centeno's theory, that the two systems are distinct in Luzon, but join each other far to the southward; and that the effects of the earthquakes on volcanoes was confined to the system of Taal on this occasion in Luzon, extending to the point where the two systems united in the south, and penetrating on its return to the north, along the system of Mayon, as far only as Bulusan, but not reaching so far north as Mayon.

The extent of these earthquakes is said to have been from Vigan to Tayabas, a distance of about 220 nautical miles in length, with an average width of about 75 miles. No shocks are reported from the extreme north or south of Luzon.

*Summary of the Seismometrical Observations taken at the Municipal Observatory of Manila, during the various earthquakes which took place from the 14th to the 25th July*, 1880.

The observations commence by a description of the instruments employed to trace the figures representing the undulations; Father Faura continues:—"The object of both apparatuses is first to discover the direction of the first horizontal undulation, which is obtained by means of the small ring at the end of the pendulum, and forced along by it.

"2nd. To ascertain the general direction of the horizontal undulations, and their amplitude by means of the lines which the same pendulum leaves in the powder.

"3rd. To obtain the greatest amplitude of the greatest vertical undulation by means of the vertical seismometer.

"4th. To obtain by a combination of the above results the magnitude and direction of the oblique undulations.

"From the indications of these two apparatuses the observations of the terrible phenomena which plunged Manila into the greatest affliction were deduced and given each day. We do not place absolute reliance in them, because the apparatuses can only offer certainty in their indications in cases where the complications and violence of the present movements are absent; but we believe they have a relative and not inconsiderable value, and that they give a sufficiently exact idea of the occurrence, for which we consider them very useful in a comparative point of view, particularly to those who have experienced the terrible phenomena.

"After these preliminary remarks, we will give the different observations collected each day, which will prove more intelligible by consulting the various figures traced by the pendulum, and these in their turn will prove a complement to those observations.

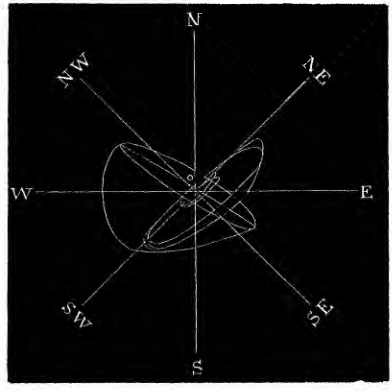
"In the months of April and May, commotions began to be felt in the northern provinces of Luzon; the centre of the seismic oscillation, according to different indications received at this station, seemed to coincide with a volcano extinct for some time, and situated between Lepanto and Abra, in the central range of Luzon, in lat. 16° 22′ N. and long. 127° E. of the Observatory of San Fernando.

"In the beginning these disturbances were weak and infrequent; but in the month of June their intensity sensibly increased, extending to the north and south in a much larger zone. The direction never changed; and if in some telegrams certain contradictions were observed, these appear to have been the effect of the haste with which the observations were taken, which can never be relied on where there are no special instruments used to mark a change in the direction of a seismic oscillation. In the beginning of July shocks were also felt; but

from the 5th to the 14th no notices of earthquakes in any part of the island were received in Manila.

"On the 14th, at 12 h. 33 m. P.M., being threatened with a storm from the north-east, indicated by an extraordinary fall of the barometer, we experienced here the first shock, in which we observed that two centres of oscillation were combined (see fig. No. 1), one on the second quadrant, from whence the pendulum of the horizontal seismo-

FIG. 1.




meter began to oscillate; and the other from the third, where the oscillation of this first movement terminated, and which was chiefly horizontal; the amplitude of total oscillation reached 5° 25′. The horizontal pendulum inscribed a cross with arms almost at right angles, the first bearing from S.E. 10° E. to N.W. 10° W.; the second from S.W. 5° W. to N.E. 5° E.

"The first impulse was in the direction from south-east to north-west. The amplitude of this oscillation described an arc of 5° 25′, and appeared to be formed by the first shock, because the pendulum almost at once oscillated in a direction almost perpendicular to the first. The amplitude of this second oscillation was somewhat less than that from the first impulse.

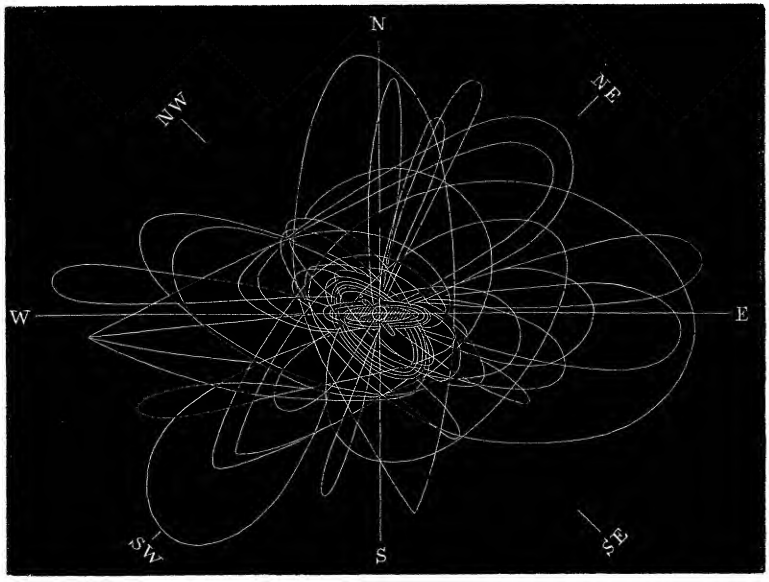
"The index of the vertical seismometer departed 4 millims. from its position. After this first movement, we experienced two more shocks in the space of an hour and a-half; on the 15th and 16th there were no perceptible movements; on the 17th, two slight shocks were felt.

"It was on the 18th, at 12 h. 40 m. P.M., when the great earthquake of oscillation, trepidation, and what is commonly called rotatory movement, occurred simultaneously. Its duration was 1 m. 10 s.

"It is impossible to describe all the movements of the pendulum on account of their number and variety. We shall therefore confine our-

selves to the principal directions with their amplitudes. All the movements are, however, to be seen in fig. No. 2.

Fig. 2.




"It is to be noted that, from our point of view, only the great oscillation from east to west (which was the most measured and free from violent shocks), indicates the true inclination of the buildings towards the west.

"1. The greatest oscillation from E. 5° S. to W. 5° N.; the amplitude of the greatest oscillation 22°, or by seismic wave motion 11° to east and 11° to west.

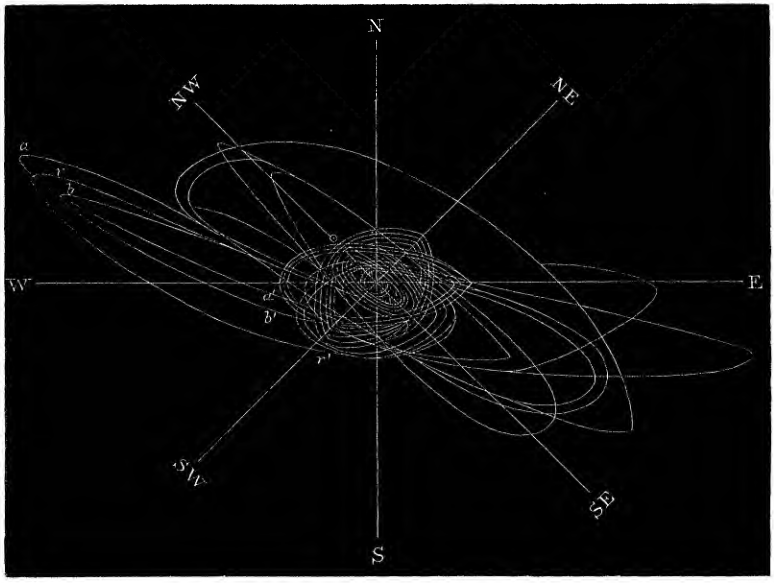
"2. Greatest oscillation from south-west to north-east, true, amplitude 19°, but with the difference of more inclination towards the south-west, which reached to 10° 10′, against 8° 50′ only towards the north-east.

"3rd. Greatest oscillation from N. 4° W. to S. 4° E., amplitude of this oscillation 16°, in which also is observed that the inclination is greater towards the south, being 9° south and only 7° north, the impulse consequently appears to be from north to south.

"The index of the vertical seismometer departed 34 millims. from its position. From the time of this earthquake until the 20th at three in the afternoon, at which time we experienced a very strong repetition, an uninterrupted series of small shocks were felt, which indicated that

we continued to be under the influence of the phenomenon. In this first repetition the oscillation and trepidation movements only were experienced, but with extraordinary violence. The oscillation of the pendulum was directed from S.E. 15° E. to N.W. 15° W. The amplitude described an arc of 12° 30′, but with the following peculiarity, that this did not consist of a perfect oscillation, but of three semi-oscillations, which show plainly the violence of the shocks (see in fig. 3 the lines marked with the letters *aa′*, *bb′*, *rr″*). The pendulum in

Fig. 3.

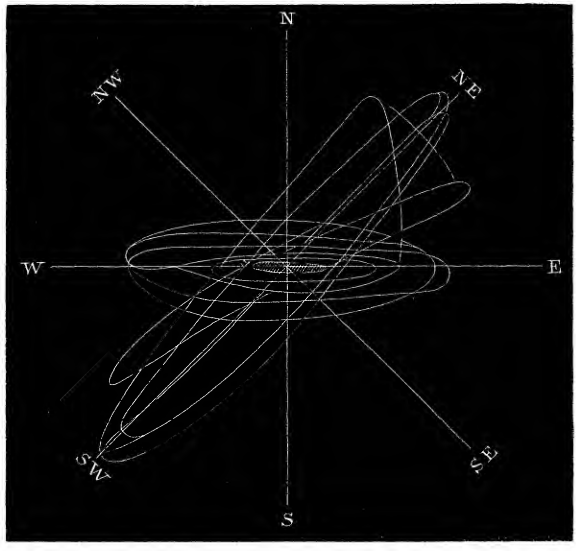



the first impulse from south-east to north-west reached the altitude indicated by the line *aa′*; on returning to its point of departure it received a new impulse which not only destroyed the velocity which it had acquired in its descent, but obliged it to ascend a second and third time almost to the same height it had attained by its first impulse.

"It is true that the inclination of the buildings was not equal to the deviation of the pendulum, but who is competent to understand the terrible convulsions which the former underwent during such repeated and violent shocks? The three above-mentioned convulsions, joined to the vertical undulation which reached 24 millims., being taken into account, the only thing to be astonished at is, that many more buildings were not thrown down. The pendulum continued oscillating during the whole of the evening from north-east to south-west.

"At 10 h. 40 m. P.M., the second, and very severe repetition took place, which, although of great violence, presented peculiarities distinct from the others; in those preceding, it was observed that the strongest focus of seismic radiation was in the second quadrant; in this latter it began, it is true, in the east, but with much less intensity than before; and the focus observed in the first quadrant continued with the same and even greater violence (see fig. 4). In this we perceive that the

FIG. 4.




oscillation from east to west, true, has an amplitude of 10° 5′ to the east, and 5° to the west; whereas, in the direction from north-east to south-west it comprises an arc of 17°: 9° to south-west, and 8° to north-east.

"The vertical seismometer marked 28 millims. Vibrations continued, but decreasing in frequency and above all in force.

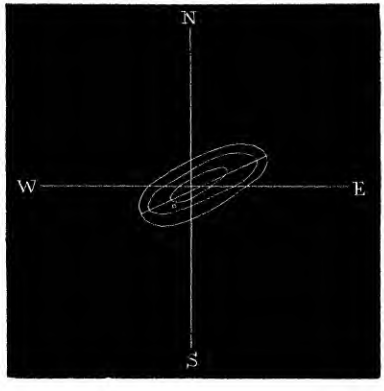
"The pendulum, which had never been at rest since the 18th until 3 P.M. of the 21st, in three succeeding days had long intervals of complete immobility. On the 25th, at 4 h. 2 m. A.M., another slight shock was felt; this, although of small intensity, we have faithfully transmitted to paper, because, in our opinion, it is important to show the gradual change of focus of seismic radiation during the whole time. The direction of the undulation was from E. 26° N. to W. 26° S., and only reached a total amplitude of 3° 45′. The movement of trepidation was inappreciable, as the index of the vertical pendulum departed only 0·7 millim. from its normal position.

"We will now recapitulate briefly what we understand by the figures.

"On the 14th, which is that represented in fig. 1, we notice two foci of seismic radiation, the first situated in the second quadrant, where it began, and the second situated in the first quadrant, where it terminated. In the earthquakes of the 18th we also discover the same two foci; but two others also appear which impelled the pendulum in every imaginable direction, as may be seen in fig. 2.

"Proceeding to that of 3 P.M. on the 20th, we find that the focus of the second quadrant acted with astounding violence, and the others disappeared (fig. 3). We turn now to fig. 4, which represents to us the violent repetition of 10 P.M. on the 20th, and we observe a great variation with regard to the foci of seismic radiation. In it we see that the oscillations from east to west, and which correspond to the focus, which before had acted with so much violence, were gradual and of much less intensity. On the contrary, that from north-east to south-west showed a great degree of undulation from these points.

FIG. 5.




"Finally, in fig. No. 5, which represents the last important oscillation on the morning of the 25th, we only note the focus of seismic radiation of the first quadrant operating with very little intensity, the other foci having entirely disappeared. We do not care at present to form deductions from the above observations, we have preferred to present them to general notice in order that scientific persons might form their own conclusions without being biassed by our opinions.

"Note 1st. Observe, that in speaking of the swing of seismic undulation from both sides of the centre of reference (place of instrument), we do not mean to say that the buildings moved from one side to the other like the pendulum, because it is very clear that the latter was only moved in *one* of the semi-undulations by the effect of the

impulse, or inclination, of the building, the *other* being the effect of the velocity acquired in the first semi-oscillation. The object of alluding to the double motion on either side of the centre of reference was to give freedom to the opinion which some people held, that earth-waves are similar to waves of sound in the air; while others aver that they are caused by the rising and sinking of the ground in localities more or less distant from the post of observation.

"Note 2nd. A great number of lines will be observed in the figures which appear not to be connected with the rest; we can only explain the fact as being caused by frequent vertical shocks, jerking the pendulum violently and causing it to leave one curve to follow another commenced by the new impulse.

"We can assure our readers that the curves as they are represented in the different figures were transferred from the lycopodium to the paper with the greatest fidelity."

This ends Father Faura's observations on the earthquakes, and in forwarding these he informs me that he will later on publish a more complete account. He is also engaged in establishing stations for meteorological observation in various parts of Luzon—which will be in telegraphic communication with Manila—and thence with Hong Kong; the chief object being to announce the advent of typhoons. As these storms invariably travel from about east by south, or east-south-east to west by north, or west-north-west, the Philippine islands, especially Luzon, are well situated for the object of giving storm warnings to the coast of China.

No doubt these stations will also be supplied with instruments, and receive instructions to observe the direction and force of earth-waves. If such stations had existed in July, the accounts would have been more complete and useful, and although reports from many places are recorded, they are in most cases unreliable and contradictory, and deal chiefly with the destruction caused to buildings, loss of life, and injury to persons.

The captain of the British steam-ship "Esmeralda," then at anchor in the Bay, states that in the earthquake at 6 P.M., on the 20th July, "the water bubbled and boiled up noisily all around the ship and the vessel tossed as if in a heavy gale;" that the wreck of a ship (which had been sunk for some years) "was thrown right up out of the water and one of her iron masts was seen to give way." He describes the sensation on board ship as well as on shore as that "of being suddenly connected with a galvanic battery strongly charged," and as being a "tremendous strain on the nerves."

Accounts are also given of fissures in the ground in various places, from which sand and water were emitted, especially in the neighbourhood of the Laguna de Bay, where hot sulphur springs have always existed.

I will now give a translation of a letter to a local paper from a resident near the spot, giving an account of the behaviour of the Volcano of Taal before and during the earthquakes of July. This letter was written in consequence of exaggerated reports of great eruptions of that volcano, and professes to give a true relation of the facts.

"The crater of the Volcano of Taal ceased to send up smoke as usual on Monday, 12th July. At nightfall on Wednesday the 14th, subterranean noises were heard, and a heavy swell was observed in the lake" (the volcano is on an island in the Lake of Taal), "which ceased after the earthquake of the same night; louder subterranean noises were heard during the earthquake.

"On Thursday the 15th, two columns of smoke continued to issue, with intervals, until the 16th, when they almost disappeared, and the volcano subsided to its usual state.

"On Sunday the 18th, in the neighbouring villages of Tanauan, Sto. Tomas, and Talisay, and nearly as far as Lipa, a fog of smoke, with smell of sulphur, was observed, which disappeared suddenly at noon; a short time after occurred the violent earthquake of Sunday, at 12 h. 40 m. P.M. In the afternoon of the same day, the 18th, the volcano again threw up the two columns of smoke, at intervals, until Tuesday the 20th, at 10 h. A.M., when it ceased smoking entirely. In the afternoon, at 3 h. and some minutes, the violent earthquake, felt at Manila, which was also most intense at Batangas and towards the Laguna, occurred. From eight to ten on Tuesday night, a brightness was seen over the volcano, as if reflecting the light of fire from the crater on the vapours which arose from it. This brightness ceased suddenly and the atmosphere cleared entirely, and at ten began the strong shocks of earthquakes, the first being the violent shock felt in Manila. These continued in the Province of Batangas" (in which Taal is situated) "during the night and were sensible for several days.

"On Wednesday the 21st, in the morning, the volcano threw up a great quantity of smoke, to a considerable height, in one column, the whole size of the crater, and continues to do so up to the time of writing this notice.

"In the evening, the Volcano of Maquiling, which had been considered extinct, gave forth much smoke, which caused terror in the province, because the people feared the crater there would break out again, and they called to mind the terrible eruption of the Volcano of Taal, on 12th December, 1754, when the lava destroyed the villages of Tanauay, Sapa, Lipa, and Taal, which villages were afterwards rebuilt in a position more remote from the volcano."

Among other strange phenomena recorded, it is stated from other sources that the great mountains of Banajoa, Maquiling, and San

Cristobal were observed at the time of the earthquake to be covered by clouds of, to all appearance, gaseous vapour; and the Padre Bravo, Curate of Lilio, asserts, that the movement of Banajoa was so awful to behold that residents of that village, situated at the base of the mountain, feared that it would fall over and bury them beneath it.

The two sheets containing diagrams of the five principal shocks were lithographed at Manila, under the careful supervision of Father Faura, and I thought it better to send them as received rather than attempt a tracing, the lines being so complicated. I have not appended a translation of the few descriptive notes on the sheets, as the terms used are almost identical with their English signification.

*February* 24, 1881.

THE PRESIDENT in the Chair.

The Presents received were laid on the table, and thanks ordered for them.

The following Papers were read:—

I. "On a Simple Mode of Eliminating Errors of Adjustment in Delicate Observations of Compared Spectra." By Professor G. G. STOKES, Sec. R.S. Received February 12, 1881.

When the identity or difference of position of two lines, bright or dark, in the spectra of two lights from different sources has to be compared with the utmost degree of accuracy, they are admitted simultaneously into different but adjacent parts of the slit of a spectroscope and viewed together. It was thus, for instance, that Dr. Huggins proceeded in determining the radial component of the velocity of the heavenly bodies relatively to the earth. It is requisite that the two lights that are to be compared should fall in a perfectly similar manner on the slit: and it will be seen, from a perusal of his paper, how careful Dr. Huggins was in this respect.

In a paper read before the Royal Society on the 3rd instant, Mr. Stone has proposed to make the observation independent of a possible error in the exact coincidence of the lights compared by constructing a reversible spectroscope, by which the light should be refracted alternately right and left, supposing for facility of explanation the slit to be vertical.

FIG. 1.

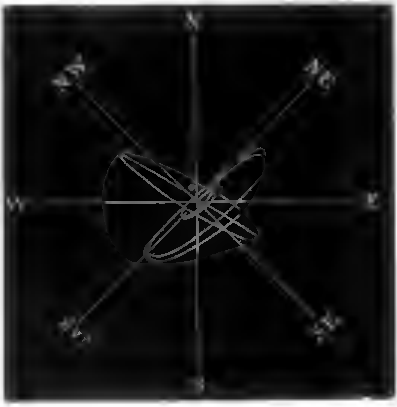


FIG. 2.

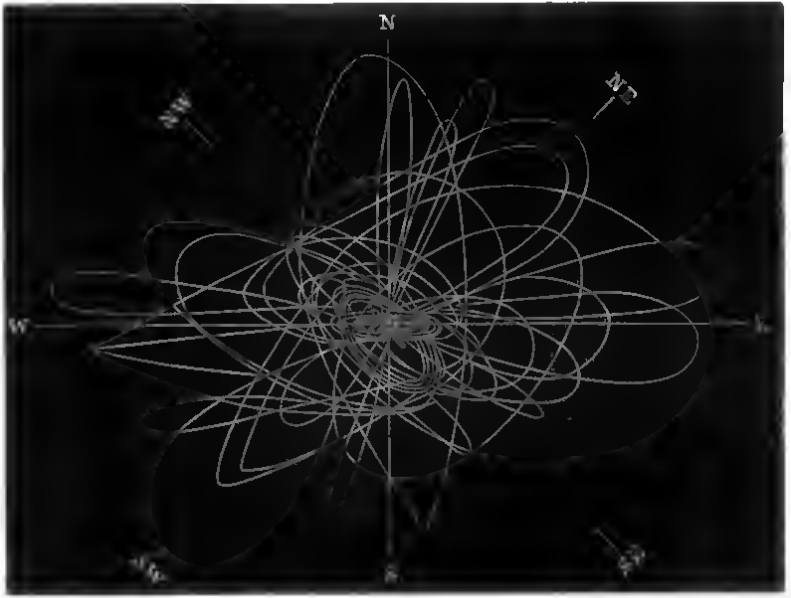


FIG. 3.

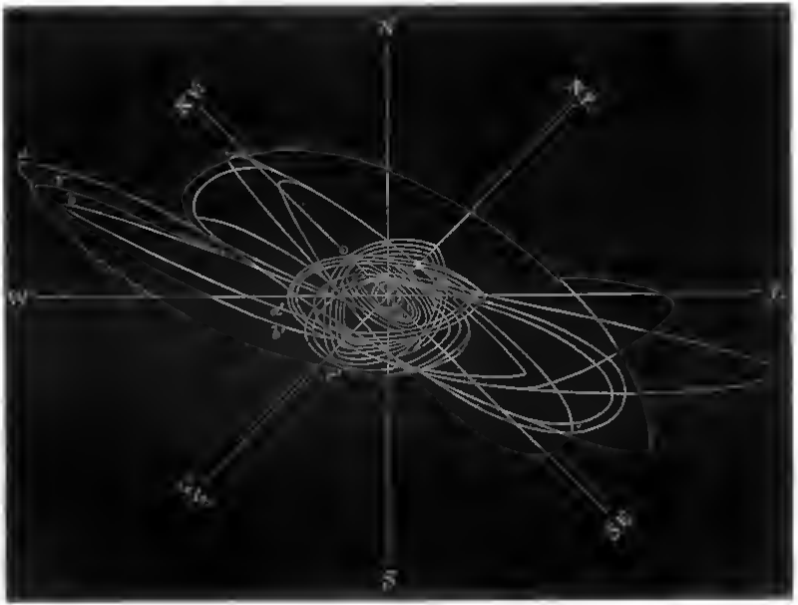


FIG. 4.

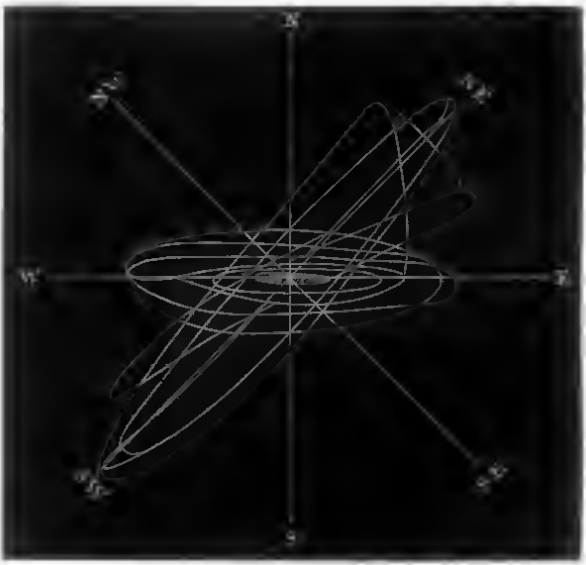


FIG. 5.